Object-Based Attention Without Awareness

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Abstract

Attention and awareness are often considered to be related. Some forms of attention can, however, facilitate the processing of stimuli that remain unseen. It is unclear whether this dissociation extends beyond selection on the basis of primitive properties, such as spatial location, to situations in which there are more complex bases for attentional selection. The experiment described here shows that attentional selection at the level of objects can take place without giving rise to awareness of those objects. Pairs of objects were continually masked, which rendered them invisible to participants performing a cued-target-discrimination task. When the cue and target appeared within the same object, discrimination was faster than when they appeared in different objects at the same spatial separation. Participants reported no awareness of the objects and were unable to detect them in a signal-detection task. Object-based attention, therefore, is not sufficient for object awareness.

Keywords visual attention, visual perception

There is an association between the phenomena of consciousness and attention so irresistible that one could readily conclude that they are inextricably part of the same process (James, 1890). As Lamme (2003) notes, both are selective: Not all visual input reaches awareness, and only a fraction of it is treated with the efficacy that is offered by selective attention. Thus, it has long been assumed that prioritization of information by attention was both necessary and sufficient for consciousness (Mole, 2008). Remarkable demonstrations of inattentional blindness, in which otherwise conspicuous visual events were rendered invisible with diverted attention, bolstered this assumption (Mack & Rock, 1998). Visual spatial attention reflects the voluntary or involuntary prioritization of information in a selected part of a visual scene (Posner, 1980). Experimentally, Posner's cuing task, in which a cue facilitates performance by speeding the discrimination of a target in the same location as the cue, has provided the benchmark measurement of covert visual attention. It has now been shown, however, that directing attention in this manner is not sufficient for generating visual awareness. In previous work (Kentridge, Heywood, & Weiskrantz, 1999), we demonstrated this in a blindsight patient who declares no awareness of visual experience in his right hemifield as a result of unilateral striate cortex damage and yet performs with remarkable accuracy in some forced-choice discriminations made within that part of his visual field (Weiskrantz, 1986). Selective attentional modulation was observed in this patient's responses to cued stimuli compared with uncued stimuli in his blind field, in very much the same way that selective attention has been seen in a normal "aware" observer in a Posner (1980) task. Similar effects have since been found in normal observers when a masked unseen prime has a greater effect on subsequent discrimination of a target when attention is directed toward it by a cue, relative to when attention is directed away from it by a cue (Kentridge, Nijboer, & Heywood, 2008; see also Sumner, Tsai, Yu, & Nachev, 2006). This experimental evidence strongly suggests that selective attention is not sufficient to give rise to awareness. In parallel, magnetoencephalographic recordings have also pointed to independent neural mechanisms regulating spatial attention and awareness in normal observers (Wyart & Tallon-Baudry, 2008). In the spotlight model of attention (Posner, 1980), selection is based on a simple spatial primitive in which attention is focused on a single point in space and spreads uniformly around it. Attention is, however, not limited to such simple, purely spatial primitives; objects of arbitrary shape can form the “units” of attentional selection (Duncan, 1984; Egly, Driver, & Rafal, 1994). Egly and colleagues (1994) demonstrated the importance of objects for the deployment of attention in the classic modification of Posner’s task, in which visual discriminations were shown to be more rapid when the target was seen to be within the same object as the preceding cue compared with when it was seen to be within a separate object, despite both cue-target pairings being equidistant. This can be explained by a model in which attentional selection operates on the elementary figures that are preattentively segmented by the visual system.1 It has been argued that in the cases of dissociation of attention from awareness, it is only spatial attention that has been manipulated, whereas awareness has been assessed typically on the basis of the visibility of objects (Mole, 2008). In other words, the unit of selection and the object of awareness may not have been truly equivalent in studies claimed to demonstrate dissociations between attention and awareness.

The motivation behind the present study was to determine whether objects can act as units of attentional selection even when they are not consciously seen. This finding would be striking, not only because object-based attention involves a level of sophistication beyond simple spatial selection, but also because the clear parity found between the objects of attention and awareness in the present experiment may be lacking in tasks solely employing simple spatial selection. In the experiment described here, objects were defined by an orientation contrast to their background, but, crucially, the orientations of the texture elements both inside and outside of the object boundaries were continually reversed. Orientation-reversing stimuli of this type have previously revealed that the perception of a border between two adjacent regions of texture persists despite the two regions being continually masked (Norman, Heywood, & Kentridge, 2011). In the present experiment, the orientations were reversed at a frequency above which the conscious perception of the contour also vanishes. We hypothesized that the contour between the objects and background may nonetheless be processed at a level that allows object-based attention, whereas any awareness of those objects would be prevented by the continual masking of the stimuli.

Participants completed a standard cuing task (Egly et al., 1994), in which they discriminated the color of a target that was validly cued (50% of trials), invalidly cued within the same object as the cue (25% of trials), or invalidly cued in another object (25% of trials). The objects appeared at unpredictable locations and assumed unpredictable orientations on a given trial (in line with rapid- and parallel-processing characteristics of objectbased attention; de-Wit, Cole, Kentridge, & Milner, 2011). Awareness was then assessed by first revealing to the participants the nature of the objects and requiring them to view the stimuli from the attention task a second time. In this second phase, however, only half of the trials contained the objects, and participants’ task was to distinguish these object-present trials from those in which the objects were absent in a confidence-rating signal detection procedure.

Method

Participants

Ten observers naive to the purpose of the experiment participated, and all gave their informed consent. Participants were undergraduate and postgraduate students recruited through the Durham University Psychology Department's participant pool and were awarded either course credit for their participation or a small financial compensation.

Materials

Stimuli were generated using a Cambridge Research Systems (Rochester, England) ViSaGe graphics system and were presented on a gamma-corrected ViewSonic (Walnut, CA) 17-in. monitor viewed at a distance of 41 cm (participants rested their head on a chin rest). The background had a luminance of 50 cdm^{-2}. The screen resolution was set to 1,024 × 768 pixels, and the monitor had a refresh rate of 100 Hz. Use of the ViSaGe graphics system ensured that stimulus display and response timing were time locked to the monitor's refresh rate.

Procedure

The experiment consisted of two phases. At the start of each trial in the first phase, participants fixated a central cross. Following a warning tone (frequency = 800 Hz, duration = 100 ms) and a delay of 500 ms, a lattice (17.2° in width and 17.2° in height) consisting of equally spaced Gabor patches arrayed in a 22 (horizontal) × 22 (vertical) grid appeared centered on the fixation cross. Each Gabor patch had a diameter of 0.4°, a spatial frequency of 3.75 cycles per degree, and an envelope with a standard deviation of 0.2°. The patches had a Michelson contrast of 90% and were separated from their neighbors by 0.4° (see Fig. 1a). These Gabor patches, each of which had a randomly determined orientation, were presented for 30 ms as a mask before the onset of the objects. Immediately following this, the patches would continually alternate between vertical and horizontal orientations at 16.7 Hz. A pair of identical rectangular objects was formed by rotating the Gabor patches in two 8 × 3 lattices such that each patch had an orientation contrast of 90° to the background. The orientation contrast of the patches in these objects remained at 90° to the background, even as the orientations of all Gabor patches in the display alternated. The flicker rate of 16.7 Hz implies that each frame was present on screen for 30 ms, which is a short duration but one that is quite typical of stimuli in forwardand backward-masking paradigms. The effectiveness of this flicker rate in concealing the objects from awareness was also verified in a number of pilot studies. Both of the objects in each pair appeared above, below, to the left of, or to the right of fixation. At least one of the objects in a pair was situated at a distance of one Gabor patch from fixation, with a distance of two Gabor patches between each object in a pair. For each block of trials, the objects were presented an equal number of times vertically and horizontally, and the order of presentation was randomized within each block. On each trial, the location of the objects was determined randomly with equal probability.

Throughout the entire grid, there were 16 Gabor positions, located in a 4 × 4 arrangement (i.e., at every fourth position, vertically and horizontally), in which the Gabor patches were absent; these gaps served as placeholders for cues or targets. This ensured that for each of the four possible object locations (above, below, left of, and right of fixation), one placeholder was located at either end of both figures, and the spatial distance between these placeholders was equated.

Two hundred fifty milliseconds after the object onset, a cue (a white disc: luminance = 158 cdm^{-2}, 0.4° in diameter) appeared for 160 ms in one of the four placeholders associated with the object positions (determined randomly with equal probability on each trial). The offset of the cue was followed by the appearance of the target disc (0.4° in diameter), which could be either red (Commission Internationale de l'Éclairage, or CIE, 1931 coordinates: $x = 0.40$, $y = 0.31$; luminance: 72 cdm^{-2}) or green (CIE 1931 coordinates: $x = 0.30$, $y = 0.59$; luminance: 81 cdm^{-2}). The color of the target was determined randomly with equal probability on each trial. The target appeared in one of three locations. In valid trials (50% of all trials), the target appeared in the same position as the cue. In invalid-within trials (25% of all trials), the target appeared in the adjacent placeholder within the same object in which the cue had been presented. In invalid-between trials (25% of all trials), the target appeared in the adjacent placeholder that was within a different object. Participants were instructed to indicate the color of the target disc (red or green) by pressing one of two buttons. The target remained on the screen until a response was made, following which the noise mask of random orientations was presented again for a further 30 ms, ending the trial. See Figures 1a and 1b for a depiction of the display sequence and a simulation of the observers' perception during the sequence, respectively. Figure 1c shows examples of the different positions and orientations that the objects could assume.

Participants completed 10 practice trials, followed by three blocks of 128 experimental trials. Participants were then asked an open-ended question to probe their visual experience of the stimuli: They were asked to describe anything they noticed about the flickering background on which the white flash (cue) and colored disc (target) were presented. After answering the question, participants were then shown the display with a much-reduced alternation rate of 4 Hz, which explicitly revealed the nature of the objects in the display.

In the second phase of the experiment, we determined whether participants were sensitive to the presence of the objects using a confidence-rating signal-detection procedure. Participants were presented with an additional three blocks of 128 trials, preceded by 10 practice trials. All randomly determined parameters (e.g., object position and orientation, when present) and temporal characteristics remained consistent with the attention task, except that objects were present in only half of the trials. When the objects were absent, all Gabor patches in the display were homogenous and alternated every 30 ms between horizontal and vertical orientations. Further, following the onset of the target, the display would remain on the screen for only a limited amount of time. This duration was automatically determined individually for each participant by obtaining their largest response time (RT) from the attention task following the removal of outliers (removal criteria are described in the Results section). The mean onset duration was 937 ms ($SD = 158$ ms, maximum = 1,280 ms, minimum = 739 ms). Participants had to indicate whether the objects were present or absent by pressing one of two keys and then rate their confidence in that judgment on a scale from 1 to 4 by pressing one of four keys.

Results

In the attention task, only trials with correct responses were analyzed. The RTs were trimmed by first removing those that exceeded 1,500 ms (which were interpreted as unsuccessful button presses or momentary lapses in concentration) or were less than 200 ms (which were interpreted as anticipatory responses). The remaining data that fell outside 2 standard deviations from the mean per condition per participant were removed as outliers. Overall, 6.2% of all trials were discarded.

A within-participants analysis of variance with cue validity as the single factor was conducted on the mean values of the remaining RTs, with overall means of 456.7 ms (valid trials), 482.9 ms (invalid-within trials), and 488.8 ms (invalid-between trials; Fig. 2a). The main effect was significant, $F(1.11, 9.95) = 25.61$, $p < .001$, Greenhouse-Geisser corrected, which indicates that the cue had a different effect on participants' RTs depending on its position relative to the target and the objects. In the key analysis, a paired t test revealed that RTs were significantly shorter on invalid-within trials than on invalidbetween trials, $t(9) = 3.41$, $p = .008$, which indicates that participants were faster to respond to targets that appeared in the same object as the preceding cue relative to those that appeared in a different object. No significant effect of accuracy (valid trials: 97.7%, invalid-within trials: 97.5%, and invalid-between trials: 98.2%) was found between conditions, $F(2, 18) = 0.48$, $p = .626$, which indicates that there was no trade-off between RT and accuracy.

In response to the open-ended question asked regarding the content of the flickering background, most participants described it as being composed of "flickering crosses" or "flickering lines," and some remarked that there were parts of the background that were "missing" (the placeholders). None, however, made any comments that could be interpreted in any way as awareness of the objects. Data from the signal-detection task were used to formally measure participants' sensitivity to the objects. The task measured participants' ability to distinguish two categories of trial (objects present and objects absent), which each occurred an equal number of times. Participants' responses were assigned to one of two categories (present or absent), and the additional confidence report by the participant on this decision (on an integer scale from 1–4) thus provided a total scale of eight responses ranging from very confident that objects were present (1) to very confident that objects were absent (8).

Sensitivity was calculated by tabulating the number of responses for each of these eight confidence levels for both objects-present and objects-absent trials. The discriminability index da was calculated from these data using the software RScorePlus (Harvey, 2002) to fit a Gaussian unequal-variance model; da assumes unequal variance and is equivalent to d' in the case of equal variance. A higher da indicates a greater sensitivity to the signal, and a da of zero indicates no sensitivity. A negative da can represent an observer's ability to discriminate the two conditions, but the conditions are labeled incorrectly by the observer (e.g., in the case of this experiment, responding consistently with the "objects-present" response for objects-absent trials, and vice versa); however, it can also simply be (and is more likely to be, in this case) a consequence of sampling error. Overall, participants' da (shown in Fig. 2b) did not differ significantly from zero (mean da = 0.01), $t(9) = 0.32$, $p = .75$, which indicates that participants could not discriminate those trials in which the objects were present from those in which they were absent; hence, it is extremely unlikely that they had any awareness of the objects. Receiver operating characteristics (ROCs) were also computed from the same data for each participant. Each curve contains 7 points (as a scale of n criteria, in this case 8, determines $n - 1$ points on the curve), with each representing a single criterion that distinguishes one rating from the immediately lower rating (e.g., Rating 4 from Rating 3, or Rating 8 from Rating 7). The ROC curves are plotted with hit rate as a function of false-alarm rate in Figure 2c; the more linear the curve, the less able the observer was to differentiate the two conditions. As Figure 2c shows, no participant displayed any ability to maximize hit rate while minimizing false-alarm rate (as would be indicated by a bowed curve), which shows that the participants could not accurately distinguish the conditions that were driving the object-based attention effects in the previous task.

Figure 2d shows each individual participant's withinobjects RT advantage (calculated as RTs on invalidbetween trials – RTs on invalid-within trials) as a function of sensitivity (da). A parametric correlation test between these two variables was not significant, $r(8) = .10$, $p = .77$, which clearly indicates that there was no association between the awareness of the objects and their effect on attention.

Discussion

In the experiment reported here, targets appearing within the same object as a cue were processed more rapidly than targets appearing in a different object. This is a standard demonstration of object-based attention (Egly et al., 1994), although participants showed no evidence of any conscious access to the objects, as revealed through a signal-detection task. This finding is in line with the more general notion that engaging attention is not sufficient for awareness, which has been demonstrated previously (Kanai, Tsuchiya, & Verstraten, 2006; Kentridge, Heywood, & Weiskrantz, 1999, 2004; Kentridge et al., 2008; Koch & Tsuchiya, 2007; Sumner et al., 2006) and that attention and awareness have distinct neural signatures (Wyart & Tallon-Baudry, 2008). The magnitudes of the withinobjects advantages reported here are small but by no means atypical of those found using this paradigm with visible objects (see Reppa, Schmidt, & Leek, 2012). Crucially, the present experiments refute the potential claims that previous work had manipulated only an early, purely spatial form of attention, in which attention is not directed at an object per se but rather simply the space that it occupies (Mole, 2008). Additionally, it is very important to note that participants' inability to detect the objects at above chance could not be attributed simply to a memory failure, as the participants were at liberty to make responses in the signal-detection task at the instant they became aware of the objects.

There are many issues to consider when choosing the most appropriate way to assess awareness in experiments that explore unconscious attentional effects (Vermeiren & Cleeremans, 2012). In the present experiment, we report the most straightforward measure—a test of participants' ability to discriminate objects' presence versus their absence. The critical property that determines the unconscious- attention effect, however, is the objects' spatial location and orientation together with the relative positions of the cue and target on each trial. Even if participants were unable to discriminate the presence and absence of objects per se, they might conceivably retain a conscious impression as to whether cues and targets appeared within a single object. It could be argued, therefore, that in the signal-detection task, participants should in fact be required to discriminate within-objects from between-objects trials on the basis that this maximizes the parity between the tasks measuring attention and awareness (Reingold & Merikle, 1988).

To address this concern, we conducted a separate experiment using the same general methods on an independent sample of 20 participants with this alternate signal-detection task. The results are reassuring, as the participants could not discriminate the two types of trial and again demonstrated a reliable within-objects RT advantage.2 Thus, we have demonstrated using two variations of a signal-detection task that both the objects' presence and their spatial relationship with cues and targets are concealed from awareness. The signal-detection task used in the present experiment is arguably the most stringent assessment of awareness, as the task has a relatively low cognitive demand; participants did not need to encode and combine separate information regarding the objects, cue, and target in order to make a successful response, as the task required knowledge concerning only the objects' presence.

An important aspect of normal object-based attention is that it is effortless and is deployed rapidly across a visual scene (de-Wit et al., 2011), which must certainly be true if these effects have any bearing on the mechanisms of everyday visual perception. It appears to be an automatic rather than a voluntarily controlled process of selection. In the present experiment, objects could appear randomly in one of four locations with a vertical or horizontal orientation. An object-based effect under these conditions is in keeping with the current understanding of the operation of automatic preattentive scene segmentation for the purposes of object-based attention. If this finding does reflect an unconscious deployment of exogenous object-based attention, it also has wider implications for understanding the relationship between attention and awareness; Chica and colleagues (2011) have shown that behavioral and electrophysiological signatures of attention and awareness dissociate when attention is voluntarily controlled, but these signatures show stronger correlation when attention is under exogenous control, which lends weight to the suggestion that awareness automatically follows exogenous attention. The results of our experiment suggest that although exogenous attention may be necessary for awareness, exogenously controlled attention can act in the absence of awareness.

The object-based attention effects observed in the present experiment stem from simple segmentation processes; however, the visual system also uses grouping principles to infer the true nature of the environment when complete segmentation information is not immediately available (i.e., when objects may be partially occluded). Consequently, object-based attention effects are still found for partially occluded objects (Moore, Yantis, & Vaughan, 1998). An important step in future research, therefore, will be to determine whether such grouping principles that extend beyond simple segmentation processes impose a limitation on the functionality of object-based attention in the absence of awareness.

The visual system is assumed to process information of an object's structure for purposes that do not automatically result in awareness. This has been illustrated in cases of visual form agnosia, in which patients have no conscious access to the shapes of objects because of bilateral damage to the lateral occipital cortex (LOC), an area selective to object shape (Grill-Spector, Kushnir, Edelman, Itzchak, & Malach, 1998). Yet, paradoxically, these patients may retain an ability to manipulate those objects appropriately in accordance with their shape (Milner et al., 1991). Such a dissociation is believed to reflect the division of labor between the dorsal (subserving unconscious guiding of action toward objects) and ventral (subserving conscious perception and recognition of objects) streams of visual processing (Milner & Goodale, 1995). Previous work (de-Wit, Kentridge, & Milner, 2009) showed that object-based attention could not be engaged in patients with bilateral LOC damage despite their having an otherwise functional attention system. This finding highlights the necessity of area LOC, a region of the ventral stream, in representing form for the purposes of object-based attention. Although the ventral stream is viewed as predominantly a conscious processing stream, there are occasions in which activity within it correlates with stimulus information despite an absence of awareness of the stimuli (Dehaene et al., 2001; Sterzer, Haynes, & Rees, 2008). Indeed, Sterzer and colleagues (2008) discovered ventral activity that differentiated images of faces from houses even when the stimuli were not entering awareness.

This high-level but unconscious categorization by the visual system is arguably a more complex process than that which determines the orientation of a pair of rectangles in an object-based attention task, and so it is not surprising to find evidence of unconscious ventral-stream operations in the present experiment. What is surprising, however, is that this unconscious ventral-stream activity is capable of directing attention. One possible explanation is that the forward and backward masking employed in this experiment substantially reduced the objectrelated activity in ventral areas to a level below the threshold of visual awareness but not below the threshold of attention. Alternatively, however, the feedback from these ventral areas to primary visual cortex may be of critical importance (e.g., see Fahrenfort, Scholte, & Lamme, 2007), something that was disrupted by the continual masking in the current experiment but that is, perhaps, not necessary for the operation of object-based attention.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Notes

1. In the current study, we did not aim to disentangle a purely object-based form of attention from one that involves the selective spreading of what is fundamentally spatial attention within an object (see Martinez et al., 2006). The only aim of the current study was to show that the process of segregating visual information into objects for the purposes of attention was not a sufficient precondition for the awareness of those objects.

2. The result of the critical paired t test between the within- and between-objects trials was $t(19) = 2.24$, $p = .037$.

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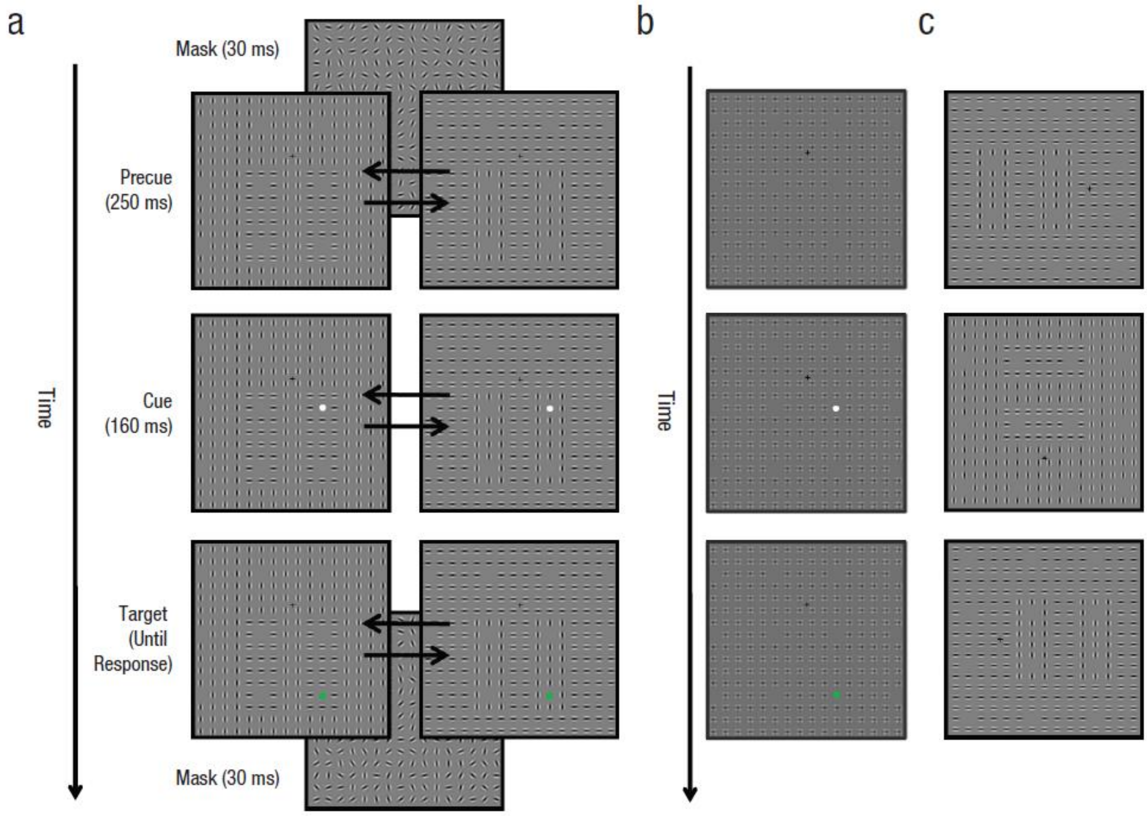

Fig. 1. Example trial sequence from the attention task (a), a simulated observer's perception of those events (b), and examples of the different object positions and orientations (c). Each trial in the attention task (a) began with a mask consisting of equally spaced Gabor patches with random orientations. After 30 ms, a pair of identical rectangular objects was formed in one of four locations (above, below, to the left of, or to the right of fixation) by rotating the Gabor patches in two 8 × 3 lattices such that each patch had an orientation contrast of 90° to the background. Objects could be vertically aligned (as shown here) or horizontally aligned. Next, a white cue appeared, followed by a red or green target appearing in one of three locations: in the same location as the cue, in the same object but not in the same location as the cue (shown here), or in the opposite object. Each box in the illustration shows only a magnified portion of the entire stimulus display, focused on the objects. Double arrows indicate that the two frames were presented continually in alternation at a frequency of 16.7 Hz. In the signal-detection task (not shown here), objects were present in only half of the trials, and the final two target frames were presented only for a limited amount of time that was calibrated for each participant. Participants were not aware of the presence of the figures, as can be seen in the simulated observer's perception of the trial sequence shown in (b). Examples of the three object positions not shown in (a) are shown in (c); from top to bottom, they are to the left, above, and to the right of fixation, respectively.

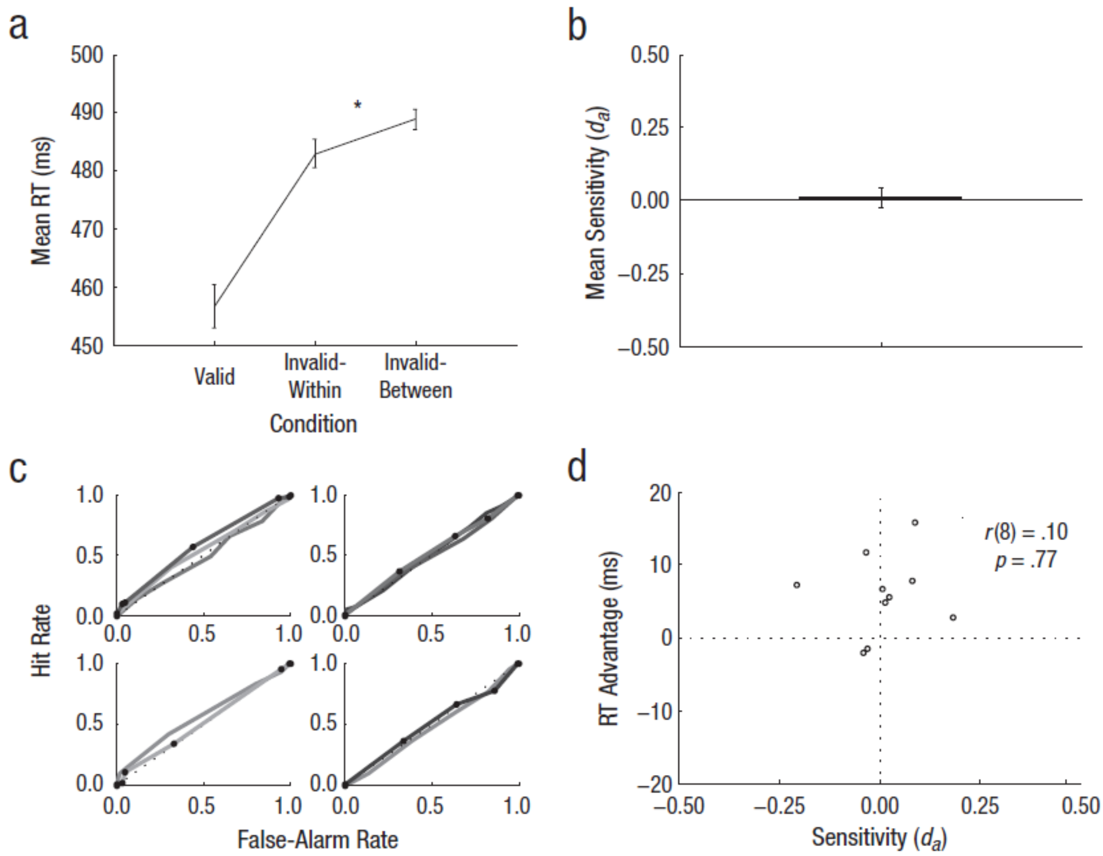

Fig. 2. Results from the attention and signal-detection tasks (N = 10). Mean response time (RT) in the attention task is shown in (a) as a function of condition. The asterisk indicates significant results between groups, as determined by a paired t test ($p < .01$). Error bars show ±1 SEM. Mean sensitivity (da) to the presence (vs. the absence) of the objects in the signal-detection task is shown in (b). The error bar shows ±1 SEM. Each participant's hit rate in the signal-detection task is shown in (c) as a function of his or her false-alarm rate. Each graph represents either 3 or 2 of the total 10 participants' receiver-operating-characteristic (ROC) curves. The scatter plot (d) shows each participant's RT advantage (calculated as RTs on invalid-between trials – RTs on invalid-within trials) in the attention task as a function of sensitivity (da) in the signal-detection task.